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Planting Date Effects on Winter Triticale Grain Yield and Yield Components

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ABSTRACT

Winter triticale (×*Triticosecale* Wittmack) has the potential to introduce valuable economic and environmental benefits to U.S. grain production systems. To maximize triticale's value, research was conducted to identify planting dates that allow maximum productivity after soybean [*Glycine max* (L.) Merr.]. Winter triticale was planted at 10-d intervals from 15 September to 15 October at three Iowa locations: central, NE, and SW, during three growing seasons: 2001–2002, 2002–2003, and 2003–2004. Grain yield decreased with planting dates after late September at the NE and SW locations in 2002–2003, and the central, NE, and SW locations in 2003–2004. Yield reductions from planting in mid October rather than late September ranged from 13 to 29%. At the NE location in 2001–2002 and the central location in 2002–2003, grain yield was 15% less for mid September than late September planting, similar for late September and early October plantings, and 13 to 15% less for mid October. Grain yield did not change with planting date at central Iowa in 2001–2002. The greatest yields occurred for planting dates where between 533 and 955 growing degree days (GDD, 0°C base temperature) accumulated between planting and 31 December. Winter triticale would most likely be placed after soybean in Iowa, suggesting that a 2-wk period would be available for planting winter triticale without diminished yield caused by late planting.

Proper planting date is important for maximizing winter cereal grain yields (Campbell et al., 1991; Dahlke et al., 1993; Witt, 1996). Growers may have to delay seeding of winter cereal grains until after the optimal date, however, to accommodate harvest of preceding full-season summer crops. Numerous studies support the fact that winter cereal grains suffer yield reduction when not planted within the optimum fall window in many climatic regions of the USA and Canada (Knapp and Knapp, 1978; Fowler, 1986; Blue et al., 1990; McLeod et al., 1992; Dahlke et al., 1993; Witt, 1996). Most of these studies have been done using winter wheat (*Triticum aestivum* L.), and, to a lesser extent, rye (*Secale cereale* L.).

Optimum fall seeding dates establish healthy and vigorous plants that allow achievement of maximum cold tolerance, complete vernalization, and optimum energy reserves for the following spring (Pittman and Andrews, 1961; Klebesadal, 1969; Fowler, 1982). A significant reduction in grain yield has been shown to occur with delayed seeding for a wide range of climatic conditions (Knapp and Knapp, 1978; Fowler, 1986; Dahlke et al., 1993). Delayed planting of winter wheat from 1 October to 1 December in Kansas decreased grain yield by 18% per month (Witt, 1996). Wheat yield declined 30 to 40% when seeding was delayed from early September to late October in SW Saskatchewan (McLeod et al., 1992). A 34% decrease in grain yield occurred when planting was delayed from 22 September to 19 October in Nebraska (Blue et al., 1990). A minimum accumulation of 400 GDD (4.4°C base temperature) between planting and 31 December was needed to produce the highest grain yields in Nebraska (Blue et al., 1990). With <400 GDD tillering decreased, leading to fewer number of spikes m^{-2} and lower grain yields. Jedel and Salmon (1994) determined that delaying planting of winter triticale from early to late September in Alberta resulted in a greater risk of grain yield reductions from winterkill.

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The number of spikes m^{-2} is often considered to be the most important yield component of winter cereal grains (Smid and Jenkinson, 1979; Blue et al., 1990). When winter wheat planting was delayed from early September to late October in Wisconsin, the number of spikes m^{-2} decreased from 580 to 238. An increased number of kernels spike^{-1} and increased kernel weight for later planting dates did not fully compensate for the lower number of spikes m^{-2} (Dahlke et al., 1993). Knapp and Knapp (1978) recorded a decrease in the number of kernels spike^{-1} for both earlier and later than optimal seeding of winter wheat in New York. Winter wheat grown in Nebraska and Wisconsin had no change in kernel numbers spike^{-1} as planting was delayed from mid September to late October and late August to early November, respectively (Blue et al., 1990; Dahlke et al., 1993).

Kernel weight is another important factor affecting final yield of winter cereal grains. Water (Royo et al., 2000) and heat stress (Gibson and Paulson, 1999) occurring after anthesis often have detrimental effects on wheat grain yield by reducing kernel weight. This is compounded by the later maturation of winter cereal grains caused by delayed planting that puts reproductive development during unfavorably hot and dry conditions (Witt, 1996). Planting date effects on kernel weight typically have less influence on final grain yield than spikes m^{-2}, but kernel weight may become more of a factor as planting is delayed (Blue et al., 1990). In Nebraska, delaying planting from mid September to late October decreased kernel weight from 28.5 to 24.5 mg kernel^{-1}. As planting was delayed, the correlation between grain yield and the number of spikes m^{-2} decreased from 0.42 to 0.08, whereas the correlation between yield and kernel weight increased from 0.38 to 0.71 (Blue et al., 1990).

Limited information is available pertaining to management and production of triticale in the U.S. Corn and Soybean Belt. Variety tests with winter triticale in Iowa

Abbreviations: GDD, growing degree days; ISU, Iowa State University; TKW, thousand-kernel weight.

(Skrdla and Jannink, 2003) and Nebraska (Baenziger et al., 2004) have shown good results with yields being greater than the highest yielding wheat cultivars. Triticale's high yields and high feeding value (Bruckner et al., 1998) show promise for introduction into the livestock rich Corn and Soybean Belt. However, there is a need to gather more information on the adaptation and management of triticale in this region. The objectives of this study were to (i) determine optimum planting dates for winter triticale, and (ii) determine the relationships among grain yield components as affected by planting date.

MATERIALS AND METHODS

Winter triticale was evaluated during 2001–2002, 2002–2003, and 2003–2004 at three Iowa locations. Trials were conducted each year in central Iowa at the Iowa State University (ISU) Bruner Farm near Ames (42.0°N, 93.6°W, 291 m) and at the ISU Northeast Research and Demonstration Farm near Nashua (43.0°N, 92.5°W, 293 m). In SW Iowa, trials were conducted at the USDA Deep Loess Research Station near Treynor (41.2°N, 95.6°W, 366 m) in 2001–2002 and 2002–2003, and at the ISU Armstrong Research and Demonstration Farm near Lewis (41.3°N, 95.1°W, 370 m) in 2003–2004. The predominate soil types were Nicollet loam (fine-loamy, mixed, superactive, mesic Aquic Hapludolls) at the Bruner Farm, Kenyon loam (fine-loamy, mixed, superactive mesic Typic Hapludolls) at Nashua, Monona silt loam (fine-silty, mixed, superactive, mesic Typic Hapludolls) at Treynor, and Marshall silty clay loam (fine-silty, mixed, superactive, mesic Typic Hapludolls) at Lewis.

Winter triticale was seeded using a no-till drill (Tye model 2007, AGCO Corp., Lockney, TX) with 10 rows spaced 20.3 cm apart. Oat (*Avena sativa* L.) was the previous crop at Ames and Nashua, and sweet corn (*Zea mays* L.) at Treynor in 2001. Soybean was the previous crop at all locations in 2002 and 2003. No tillage was performed unless previous production practices left the soil surface unsuitable for planting. Minimum tillage (field cultivation) was performed at all locations in 2001, at Treynor in 2002, and at Lewis in 2003. The seeding rate was 330 kernels m^{-2} for all years and locations. Plot size was 5.9 by 15.2 m. Targeted planting dates were 15 September, 25 September, 5 October, and 15 October. Actual planting dates are listed in Table 1. The SW location was abandoned in 2001–2002 due to severe lodging, and late soybean harvest at Nashua in 2002 resulted in only the latter three dates being planted.

In 2001, 'Pika' was planted at Ames, Nashua, and Treynor. In 2002, 'Trical 815' and 'DANKO Presto' were both planted at Ames and Nashua, while only Trical 815 was planted at Treynor. The cultivar switch was made because variety testing in 2002 demonstrated that DANKO Presto and Trical 815 were better suited than Pika for grain production in Iowa. For 2003, Trical 815 and DANKO Presto were planted at Ames, Nashua, and Lewis. In ISU variety tests from 2002 to 2004, Pika headed about 9 d later than Trical 815, which headed 1 d later than DANKO Presto. Nitrogen fertilizer, in the form of urea, was applied at 23 kg N ha^{-1} at all locations during the spring 2002 before initial green-up of the triticale. No N was applied at any site in 2003. In the spring 2004, 14 kg N ha^{-1} was applied in the form of ammonium nitrate at Lewis because soybean residue was removed before planting.

Daily maximum and minimum temperatures were recorded during the growing season (planting to 31 December and 1 March to harvest) at each location using an on-farm weather station. Mean climatic conditions were obtained from the Iowa Environmental Mesonet (Iowa Environmental Mesonet, 2004) for each site. Growing degree days (0°C base temperature) were calculated by using the equation

$$\text{GDD} = \Sigma\ \{[(\text{daily maximum temp.} + \text{daily minimum temp.})/2] - \text{base temp.}\} > 0$$

Data Collection

Grain was harvested with combines equipped with on-board electronic weighing systems from areas ranging from 3.66 to 4.57 m wide by 15.24 m long, depending on the combine platform size. Grain subsamples (approximately 2000 g) were taken during the combine harvest to determine 1000-kernel weight (TKW), moisture concentration, and test weight. Samples were cleaned to remove foreign material using a seed cleaner (Office Model Clipper, Ferrel Ross, Bluffton, IN) fitted with a 16-mm round and 1.06- by 12.7-mm slotted screens. A thousand kernels were counted with a seed counter (Model 850–2, The Old Mill Co., Savage, MD) and then weighed to determine TKW. Test weight and moisture concentration were determined using a grain analysis computer (Model GAC2100, Dickey-John, Auburn, IL). Final grain yields were adjusted to 135 g kg^{-1} moisture. Relative yields were calculated within locations and growing seasons by dividing mean grain yield for a planting date by the mean grain yield of the highest-yielding planting date and multiplying by 100.

The number of plants m^{-2} was determined from two 0.33-m^2 samples taken from each plot when average fall temperatures reached 4°C. Ten random plants were then selected from the sample and the number of tillers plant^{-1} was counted. The product of the number of plants m^{-2} and the number of tillers plant^{-1} resulted in the number of fall-produced tillers m^{-2}. The number of spikes m^{-2} was determined by sampling one-meter

Table 1. Targeted and actual planting dates of winter triticale for three Iowa locations and three growing seasons.

		Actual planting date		
Location†	**Targeted planting date**	**2001–2002**	**2002–2003**	**2003–2004**
Central	mid September	14 September	13 September	17 September
	late September	25 September	24 September	26 September
	early October	4 October	8 October	7 October
	mid October	15 October	17 October	16 October
Northeast	mid September	18 September	–	16 September
	late September	25 September	23 September	25 September
	early October	4 October	7 October	6 October
	mid October	17 October	16 October	16 October
Southwest	mid September	13 September	16 September	15 September
	late September	25 September	25 September	24 September
	early October	3 October	9 October	5 October
	mid October	15 October	18 October	15 October

† Central: Ames in 2001–2002, 2002–2003, and 2003–2004; Northeast: Nashua in 2001–2002, 2002–2003, and 2003–2004; Southwest: Treynor in 2001–2002 and 2002–2003, Lewis in 2003–2004.

of row from two areas of each plot (0.406 m^2) just before combine harvest and counting total number of spikes. The number of kernels $spike^{-1}$ was determined from samples collected on the day of combine harvest. Kernels were counted after ten consecutive spikes were taken from two areas of each plot, combined, and threshed by hand to remove all kernels.

Statistical Design and Analysis

The experimental layout was a randomized complete block with four replications, repeated in 3 yr at three locations—central, NE, and SW Iowa. Proc Mixed of SAS (Littell et al., 1996, p. 1–29) was used to compute *F* tests and standard errors for all main effects and two-way and three-way interactions between years, locations, and planting dates on grain yield, fall tillers m^{-2}, spike m^{-2}, kernel $spike^{-1}$, and TKW. Because there was a shift in cultivar after 2001–2002 and only one cultivar was grown at the SW location in 2002–2003, cultivar was not included as a parameter in the ANOVA model. Data for cultivar was combined when two cultivars were grown at a location in a particular year. Location, planting date, and their interaction were treated as fixed effects, whereas years and interactions with years were random using ANOVA estimates (Method = Type 3) of the variance components. Appropriate error terms were based on the expected mean squares. Because of unequal sample sizes, the appropriate error terms were linear combinations of mean squares. The error term to test the main effects of location was primarily the year $\times$ location interaction, the error term to test the main effects of planting date was primarily the year $\times$ planting date interaction, and the error term to test the location $\times$ planting date interaction was primarily the year $\times$ location $\times$ planting date interaction. Degrees of freedom were estimated using the Satterthwaite approximation. Significance level for all statistical tests was $P = 0.05$.

Relative grain yield was calculated as the percentage yield level based on the mean of the highest yielding planting date within a location and growing season. Regression analysis was performed using the relative yield values plotted as a function of the number of fall GDD accumulated after each planting date (Steel and Torrie, 1980, p. 452–468).

RESULTS AND DISCUSSION

Weather Conditions

Climatic conditions (Tables 2 and 3) were favorable for high grain yield of triticale during 2001–2002 and 2002–2003. The 2003–2004 growing season was dominated by cool and moist conditions that increased the presence of *Septoria* leaf blotch (*Septoria* spp.) at all locations (Wiese, 1987, p. 43–45). Mean fall temperatures were slightly above average in 2001 and below average in 2002 and 2003 (Table 2). Winter temperatures were above average in 2001–2002 and typical for each location in 2002–2003 and 2003–2004. There were no distinctly visible stand losses from winter injury at any of the study locations in any of the three growing seasons. Temperatures during grain fill (June to mid July) were warmer than average in 2002, average in 2003, and below average in 2004. Fall precipitation was above average in 2001 and average in 2002 and 2003 (Table 3). Precipitation during the period of May to mid July was above average for all seasons. The bulk of the precipitation for this period, however, occurred in early May for 2003; whereas, it came in mid May and continued to be above average through June in 2004.

Grain Yield

Planting date effects on winter triticale grain yield varied with year and location (Table 4, Fig. 1). Grain yield decreased with planting dates after late September at the NE and SW locations in 2002–2003 and the central, NE, and SW locations in 2003–2004. Yield

Table 2. Mean daily temperature averaged for two week periods for the locations and growing seasons of the study.

	2001–2002			2002–2003			2003–2004			Mean temperature†			
Date	Ames‡	Nashua	Treynor	Ames	Nashua	Treynor	Ames	Nashua	Lewis	Ames	Nashua	Treynor	Lewis
	°C												
1–14 September	18.6	17.5	20.4	21.4	20.7	22.4	19.5	19.6	19.8	20.6	18.6	20.5	19.3
15–28 September	14.5	13.4	15.4	15.3	14.5	16.0	13.4	13.2	14.7	16.8	14.7	16.6	15.4
29 September–12 October	12.8	11.9	14.3	14.3	13.8	15.0	13.6	12.5	14.5	14.4	12.4	14.2	13.0
13–26 October	8.3	7.4	9.7	4.6	3.8	5.1	11.3	9.8	12.2	11.9	9.6	11.6	10.2
27 October–9 November	10.8	9.7	12.5	3.0	2.8	3.7	1.5	0.7	2.4	7.7	5.4	7.1	5.8
10–23 November	10.0	8.8	11.1	1.9	1.0	2.4	4.4	3.5	5.7	4.5	1.6	4.0	2.6
24 November–7 December	4.1	4.1	3.6	−4.3	−5.3	−1.1	−1.3	−1.8	0.0	−1.5	−2.9	0.1	−1.4
8–21 December	1.2	0.2	–§	0.3	−0.9	1.7	−4.4	−5.8	−3.3	−5.3	−6.6	−3.7	−5.0
22 December–4 January	−8.3	−10.0	–	−2.5	−3.9	−1.6	−0.9	−2.1	−0.2	−6.5	−8.0	−4.9	−6.2
5–18 January	−1.3	−2.8	–	−6.2	−7.4	–	−6.3	−6.9	−5.4	−8.0	−9.6	−6.3	−7.6
19 January–1 February	−0.9	−0.7	–	−8.7	−10.4	−7.7	−12.8	−13.6	−11.2	−7.7	−9.5	−5.5	−6.9
2–15 February	−3.2	−3.3	−1.9	−7.6	−9.8	−4.6	−10.5	−11.2	−10.9	−5.9	−7.6	−3.9	−5.5
16–28 February	0.6	−0.4	–	−6.9	−6.5	−5.9	0.6	−0.8	1.4	−2.7	−4.3	−0.9	−2.2
1–14 March	−3.3	−4.5	−2.1	−5.9	−6.9	−3.3	3.0	1.2	3.6	1.4	−1.9	1.3	−0.1
15–28 March	0.8	−0.1	1.2	8.4	7.6	7.2	6.4	5.8	7.1	4.4	1.3	4.5	3.1
29 March–April	5.1	3.7	7.2	5.9	3.3	6.8	6.6	6.1	7.9	8.1	5.7	8.2	7.4
12–25 April	12.6	12.0	14.3	12.2	11.4	13.6	12.1	11.0	12.9	11.6	9.6	11.5	10.5
26 April–9 May	11.5	10.7	12.7	12.8	12.5	13.9	13.8	12.8	15.2	14.4	12.7	14.4	13.3
10–23 May	11.9	11.4	13.3	13.9	13.5	14.3	17.0	16.0	17.4	17.0	15.6	17.1	16.2
24 May–6 June	19.5	18.2	21.3	17.0	16.4	17.8	17.5	16.9	18.3	18.6	17.4	19.0	18.1
7–20 June	21.8	21.3	23.1	20.4	19.9	20.7	21.2	20.9	21.3	21.7	20.3	22.0	21.1
21 June–4 July	25.5	25.2	26.3	22.5	22.3	23.3	18.8	18.6	19.6	23.1	21.7	23.5	22.5
5–18 July	23.4	22.8	24.8	22.3	21.0	24.8	21.0	20.4	22.1	24.3	22.5	24.4	23.4
19–31 July	25.0	24.0	26.0	22.0	21.5	23.5	20.8	20.4	21.5	24.4	22.4	24.4	23.3

† Mean temperatures from 1951 to 2004 were obtained from the Iowa Environmental Mesonet. Data for Ames, Nashua, Treynor, and Lewis was obtained from stations at Ames, Charles City, Glenwood, and Atlantic, respectively.
‡ Seasonal temperature data was obtained from on farm weather stations at Ames, Nashua, Treynor, and Lewis.
§ A dash (–) indicates no measurement was available.

Table 3. Average precipitation for 2-wk periods for the growing seasons and locations of the study.

	2001–2002			2002–2003			2003–2004			Mean precipitation†			
Date	Ames‡	Nashua	Treynor	Ames	Nashua	Treynor	Ames	Nashua	Lewis	Ames	Nashua	Treynor	Lewis
	mm												
1–14 September	99	104	40	3	8	9	38	22	15	56	53	69	76
15–28 September	35	29	26	30	40	11	49	25	34	46	51	58	51
29 September–12 October	17	10	26	42	34	63	7	9	8	46	41	46	46
13–26 October	38	25	36	19	11	11	8	6	9	43	43	51	48
27 October–9 November	2	2	3	13	9	10	12	3	39	41	33	48	43
10–23 November	2	9	6	1	4	0	0	0	0	36	33	41	53
24 November–28 February§	–	–	–	–	–	–	–	–	–	150	127	173	175
1–14 March	0	0	0	0	0	1	0	0	0	30	28	33	36
15–28 March	0	0	2	0	0	10	0	0	0	36	30	43	41
29 March–11 April	20	26	12	6	7	14	0	0	0	36	33	41	36
12–25 April	27	33	20	8	37	26	45	43	45	43	43	46	43
26 April–9 May	53	51	42	101	116	90	15	22	34	48	46	53	51
10–23 May	80	22	43	18	19	27	115	180	109	51	51	56	51
24 May–6 June	33	57	16	23	56	30	55	73	52	53	43	64	53
7–20 June	57	29	45	17	37	25	50	42	44	64	51	64	58
21 June–4 July	14	15	6	26	71	35	42	57	68	71	64	76	61
5–18 July	108	51	59	56	50	20	27	75	43	69	58	64	61
19–31 July	12	84	22	28	9	6	5	32	39	56	58	64	53
Precipitation totals¶	596	545	400	389	506	387	466	590	539	673	632	732	683

† Mean precipitation from 1951 to 2004 was obtained from the Iowa Environmental Mesonet. Data for Ames, Nashua, Treynor, and Lewis was obtained from stations at Ames, Charles City, Glenwood, and Atlantic, respectively.
‡ Seasonal precipitation totals were obtained from on farm weather stations at Ames, Nashua, Treynor, and Lewis.
§ Winter precipitation was not measured.
¶ Combined precipitation for the 1 September to 23 November and 1 March to 31 July periods.

reductions from planting in mid October rather than late September were in the range of 13 to 29%. At the NE location in 2001–2002 and the central location in 2002–2003, grain yield increased by 15% with the 10-d delay in planting from mid September to late September, was similar for late September and early October plantings, and declined by 13 to 15% as planting was extended to mid October. Grain yield did not change with planting date at central Iowa in 2001–2002.

Variation in grain yield response to planting date with location and year was likely caused by variability in climatic conditions. Winter triticale grain yield was maximized at accumulation of 744 GDD (base 0°C; Fig. 2). However, at least 95% yield was achieved with as few as 533 GDD and as many as 954 GDD. The yield reduction from late planting may be due to the plants being unable to attain optimum energy reserves, leaf area, or fall tillers for growth the following spring (Pittman and Andrews, 1961; Klebesadal, 1969; Fowler, 1982).

There was considerable variability in grain yield across years and locations (Fig. 1). The greatest yields, which neared 7 Mg ha^{-1}, occurred for September planting in SW Iowa in 2003, whereas the lowest yields (1.67 Mg ha^{-1}) were for mid October planting at central Iowa in 2004. Average grain yields within a location were different by as much as 56, 20, and 46% across seasons at central, NE, and SW locations, respectively (Fig. 1). The change in cultivars from Pika to DANKO Presto and Trical 815 after the 2001–2002 may have contributed to grain yield differences among years. However, large grain yield differences between 2002–2003 and 2003–2004, when DANKO Presto and Trical 815 were grown, indicated that seasonal climate greatly influenced yield. Southwestern Iowa was generally a better environment for winter triticale production than central and NE Iowa, although there were no differences in grain yield between the SW and NE locations in 2003–2004 (Fig. 1). Grain yields were greater for central than NE Iowa in 2001–2002 and 2002–2003, but

Table 4. Mean squares and *F* values for grain yield and yield components of winter triticale grown at three Iowa locations in three growing seasons.

			Yield component									
			Grain yield		Fall tillers m^{-2}		Spikes m^{-2}		Kernels spike^{-1}		1000-kernel weight	
Source of variation	d.f.	Random or fixed	MS	*F* value	MS	*F* value	MS	*F* value	MS	*F* Value	MS	*F* value
			Mg ha^{-1}								g	
Year (Y)	2	R	68.91	4.99	865698	1.70	146919	1.37	507.5	8.15	940.26	9.14**
Location (L)	2	F	21.26	1.47	16020	0.04	156858	1.39	701.1	11.76**	356.19	3.87
Y × L	3	R	14.43	15.96***	469754	2.26	112943	15.38***	59.9	1.78	91.88	8.86**
Block within Y × L	24	R	0.32	2.85***	24079	0.89	3620	1.62**	24.5	1.29	7.25	2.13**
Planting date (P)	3	F	3.15	6.29*	10610478	51.50***	50771	13.59**	81.2	2.64	1.59	0.08
Y × P	6	R	0.55	0.81	1391666	1.21	3948	0.68	31.9	1.14	20.49	3.09
L × P	6	F	0.77	1.11	30993	0.17	4718	0.79	47.3	1.67	5.24	0.77
Y × L × P	8	R	0.71	6.22***	200780	7.42***	6053	2.70**	28.5	1.50	6.85	2.01*
Error	145		0.11		27075		2241		18.9		3.41	

* Significant at $P = 0.05$.
** Significant at $P = 0.01$.
*** Significant at $P = 0.001$.

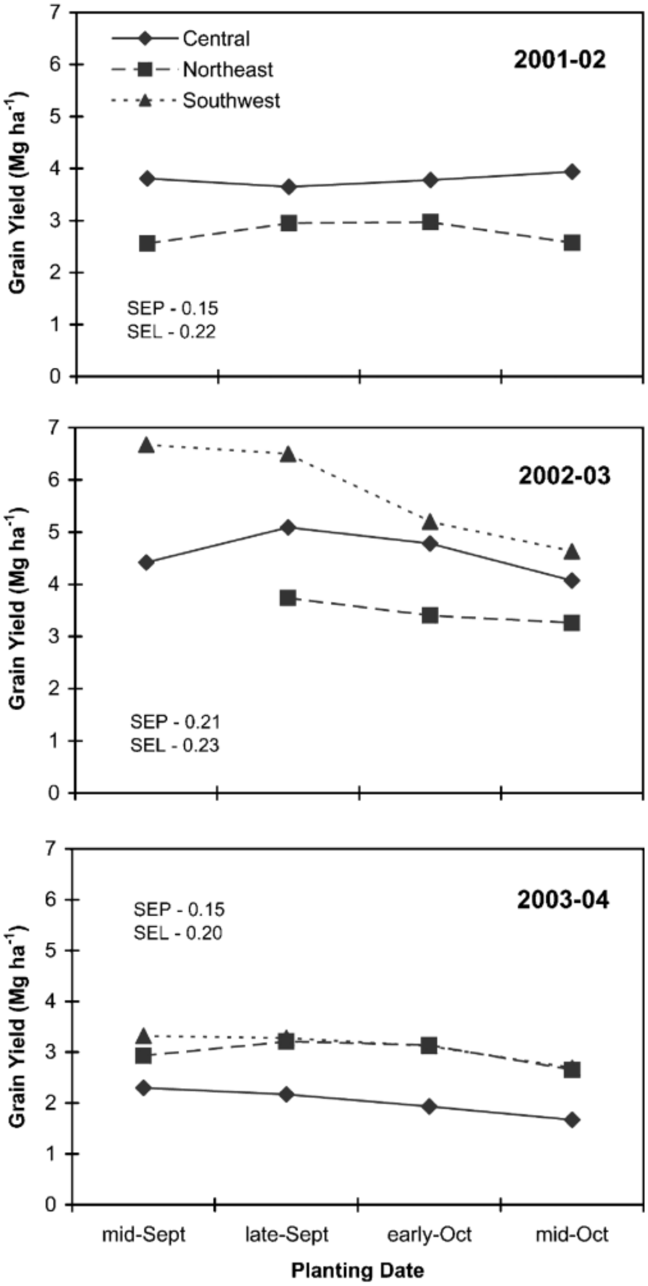

Fig. 1. The effect of planting date on winter triticale grain yield at three Iowa locations in three growing seasons. SEP = standard error for comparison between two planting dates within a location and year; SEL = standard error for comparison between two locations for a planting date within a year.

less at central than NE Iowa in 2003–2004 (Fig. 1). A combination of poor drainage, soil compaction, and suspected nitrogen deficiency reduced grain yields at the central location in 2003–2004.

Yield Components

Fall tillers m^{-2}, spikes m^{-2}, and TKW response to planting date varied with year and location (Table 4, Fig. 3). Kernels spike^{-1} differed by location, but was unaffected by planting date or year (Table 4). Triticale grown in SW Iowa averaged 42 kernels spike^{-1} averaged across years and

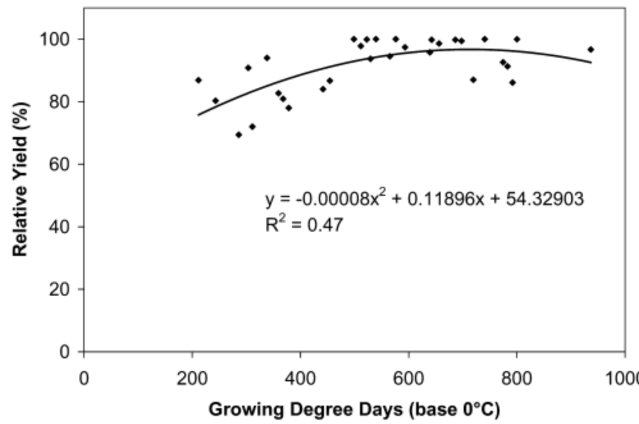

Fig. 2. Effect of planting date on relative yield of winter triticale grown during three growing seasons at three Iowa locations. Relative yields are based on mean grain yield of the highest yielding planting date within each location and growing season. All components of the equation were significantly different from zero.

planting dates, which was greater than 36 kernels spike^{-1} at central and NE Iowa. Conclusions regarding year and location effects must be made with caution since cultivars were changed after the 2001–2002 growing season and only one cultivar was grown at the SW location in 2002–2003. However, data trends (Fig. 1 and 3) suggested differences in growing conditions among seasons, locations, and planting dates had a greater influence on partitioning to the various yield components than cultivar differences.

Planting date had the greatest influence on fall tillers, which decreased significantly with each 10-d planting delay from mid September to mid October at all locations in 2001–2002 and 2003–2004 (Fig. 3). There were almost no fall tillers in mid October plantings. A similar response was observed as planting date was delayed from mid September to early October in 2002–2003 (Fig. 3). Tillering was very low, however, for both the early and mid October plantings due to colder than average air temperatures in October and early November (Tables 2 and 3). Location effects on fall tillering were significant for most September plantings, but not for October plantings (Fig. 3). The locations with the greatest amount of fall tillers for September plantings differed by year suggesting that temperature was not the only factor influencing fall tiller formation.

The number of spikes was maximized at about 500 m^{-2} by planting in September or early October at NE Iowa in 2001–2002, central and SW Iowa in 2002–2003, and SW Iowa in 2003–2004 (Fig. 3). Spike numbers also were greatest for mid September to early October plantings in most other cases, except at the central location in 2001–2002, where there was no response to planting date. However, spike numbers at the central location in 2001–2002 and 2003–2004 and the NE location in 2002–2003 and 2003–2004 were less than the maximum for most planting dates (Fig. 3). The number of fall tillers m^{-2} were greater than the number of spikes m^{-2} produced for mid September planted triticale, suggesting that all reproductive structures may have originated from fall-produced tillers. Late September plantings produced a similar number of fall tillers and spikes (Fig. 3). When

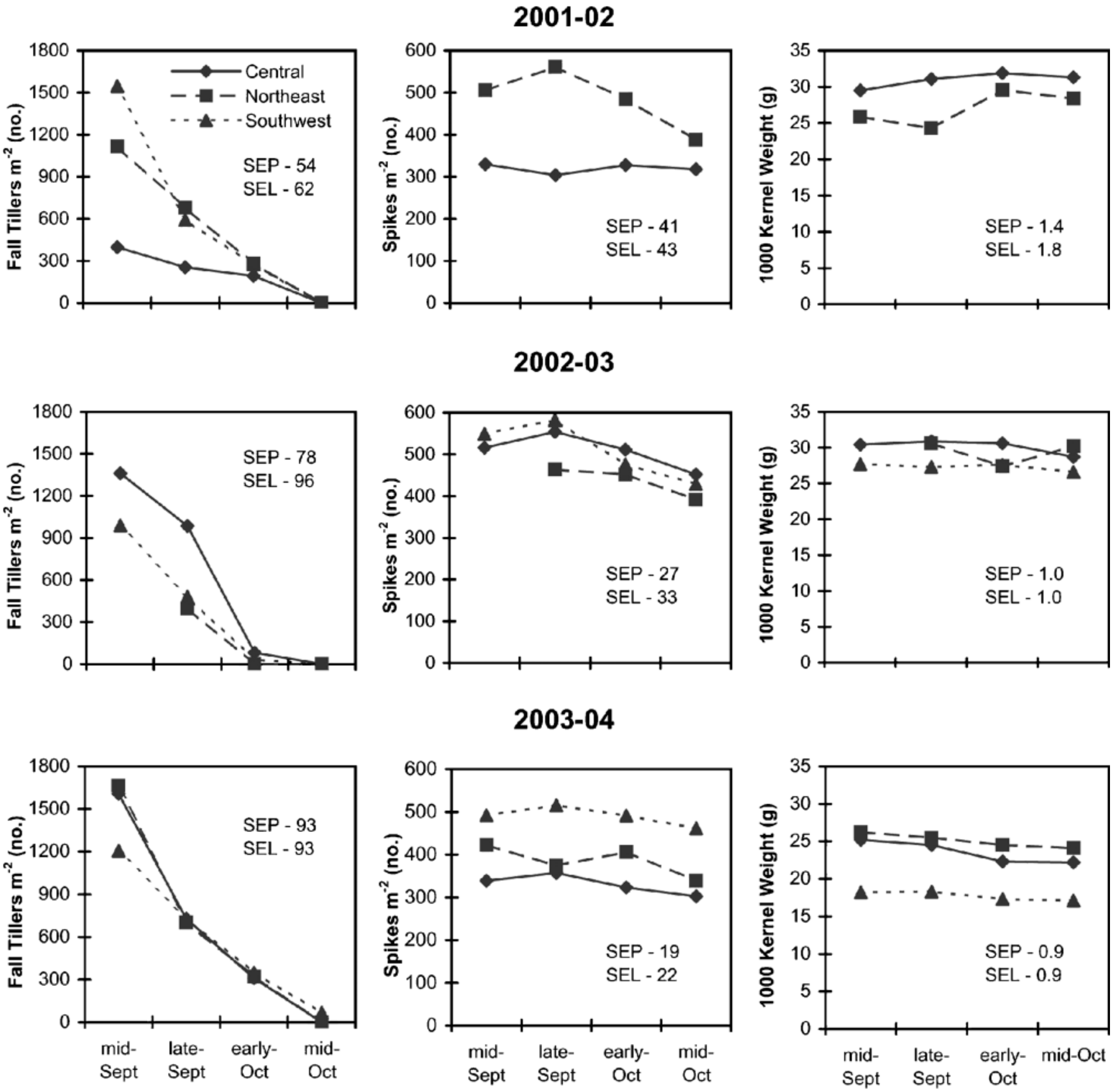

Fig. 3. Planting date effects on fall tillers plant^{-1}, spikes m^{-2}, and 1000-kernel weight of winter triticale at three Iowa locations in three growing seasons. SEP = standard error for comparison between two planting dates within a location and year. SEL = standard error for comparison between two locations for a planting date within a year.

triticale was planted in October, the number of fall tillers m^{-2} was less than the number of spikes m^{-2}. Spring tillering allowed early October plantings to produce numbers of spikes similar to September plantings. However, lack of fall tillering could not be fully compensated by spring tillering in mid October plantings, resulting in fewer spikes m^{-2} and reduced grain yields (Fig. 3). Reproductive structures created from spring tillers were possibly later and more variable in maturity than fall tillers, which could have also contributed to lower grain yields (Gallagher, 1984).

Thousand-kernel weights did not differ across planting dates at the central location in 2001–2002 and 2002–2003 or the SW location in 2002–2003 and 2003–2004 (Fig. 3). It increased by 15% as planting was delayed from late September to October at the NE location in 2001–2002, but decreased by about 6% for a similar delay at the central and NE locations in 2003–2004. Differences in kernel weight between the NE and central locations within years were generally 15% or less and the location with the heavier kernels varied by year (Fig. 3). The SW location had lighter kernels than the central or NE locations for most planting dates in both 2002–2003 and 2003–2004.

Heat stress is known to have a detrimental effect on kernel weight in wheat (Warrington et al., 1977; Tashiro and Wardlaw, 1990; Gibson and Paulson, 1999) and may serve as an explanation for several of the reductions in triticale kernel weight in our study. In 2001–2002, heat stress occurred in late June (Table 2), affecting grain filling in earlier-maturing September-planted triticale at the NE location. Triticale planted later experienced less heat stress during grain fill due to later maturation and cooler temperatures after the short period of high temperatures. Reduction in kernel weight at the SW location in 2002–2003 was likely due to warmer temperatures during grain filling there relative to the central and NE location (Fig. 3). Reductions in kernel weight with late planting at central and NE Iowa in 2003–2004 was more likely to have been caused by the high incidence of *Septoria* leaf blotch than heat stress. The *Septoria* infection may have resulted in lower kernel weights for the later planted triticale because it was later maturing than the earlier planted triticale.

The drastic reductions in kernel weight and grain yield at the SW location in 2003–2004 were surprising and could not be entirely explained by *Septoria* infection. The number of spikes m^{-2}, kernels $spike^{-1}$, and average kernel weight in other years and at other sites, and the visual appearance of the crop at harvest all suggested a grain yield potential in excess of 6 Mg ha^{-1}. The extremely poor kernel weight, however, resulted in actual yields that were 40% less than this potential. More so than the other two locations, SW Iowa had repeated wetting and drying of the spikes and high night temperatures during grain maturation, which may have contributed to shriveling and shrinking of the kernels.

Spikes m^{-2} was the yield trait most affected by delayed planting with a reduction of 50 to 200 spikes m^{-2}, whereas kernel weight and kernel number $spike^{-1}$ were generally not affected by planting date (Fig. 1 and 3). A similar response has been reported for winter wheat (Smid and Jenkinson, 1979; Blue et al., 1990). Previous research suggests that increasing seeding rate may partially offset reduced yields caused by delayed planting. Yield losses caused by late planting were diminished when seeding rate of wheat was increased from 300 to 452 kernels m^{-2} (Dahlke et al., 1993) and from 34 to 101 kg ha^{-1} (Blue et al., 1990). Application of P fertilizer to low P testing soils also can lessen the yield loss associated with delayed planting (Blue et al., 1990). Phosphorus levels of soils used in this study were not tested. Greater plant numbers from the higher seeding rate compensate for the loss of tillers and number of spikes m^{-2} that occur with late planting at lower seeding rates, whereas applying phosphorus fertilizer stimulates tillering, resulting in a greater number of spikes m^{-2} (Blue et al., 1990).

CONCLUSIONS

Winter triticale would most likely be planted after soybean in the U.S. Corn and Soybean Belt. Our results suggest there would be a 2-wk planting window for winter triticale after the start of soybean harvest in Iowa without diminished yield potential from late planting. On the basis of mean historical temperatures and a 533 GDD (base 0°C) threshold for achieving 95% yield potential, triticale planting should occur on or before 27 September, 23 September, and 3 October in central, NE, and SW Iowa, respectively, to achieve maximum grain yield potential. A decrease in grain yield would occur as planting was delayed past these dates with a 20% reduction if planting was delayed until mid October.

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